Stretching Table Salt into Superplastic Nanowires

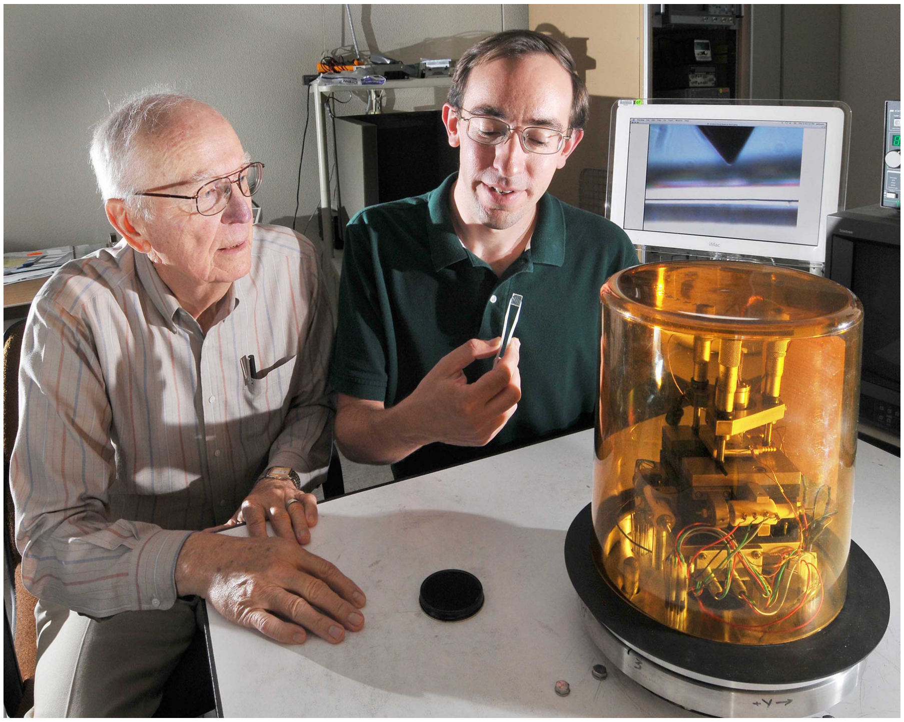

Figure 1: Two of the Sandia researchers, Jack Houston (left) and Nathan Moore (right) examine a salt crystal studied in the IFM instrument (foreground) using the diamond probe tip (magnified on screen, back).

Normally brittle material stretches like taffy in the nanoworld

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Although everyone is familiar with common salt (sodium chloride), relatively little is known about how it impacts daily lives at the length scales of atoms and molecules. Ions and nanometer-sized crystals of sodium chloride play key roles in applications like water purification, the stability of rock salt for carbon sequestration and underground nuclear waste disposal, and for seeding atmospheric reactions. For example, it is now recognized that changes in crystal morphology can affect the reactions of sea salt aerosols, which have been implicated in problems as broad as smog formation, ozone destruction, and triggering asthmatic responses in humans.

Experiments originally aimed at understanding how water bonds to salt surfaces for desalination applications led to the surprising discovery that superplastic nanowires were being pulled from the surface of ordinary table salt. In the initial experiments, the Sandia-developed interfacial force microscope (IFM, Figure 1) showed an unusual adhesive force when a sharp diamond tip approached within a few nanometers of a salt crystal. This adhesive force remained as the tip withdrew, suggesting that the tip was pulling long tendrils of salt from the crystal surface. Similar adhesion experiments with sharp gold tips in a transmission electron microscope (TEM) confirmed that superplastic nanowires were being pulled from the salt surface (Figures 2, 3). The nanowires stretched ~2.2 μm, or 280% of their original length, and could be bent >90° upon compression. The nanowires necked down, rather than fracturing, as if the salt crystal were more akin to chewing gum than a rigid solid.

Superplasticity, or elongation to failure >100%, is a rare material property at room temperature, and even more rare for ionic crystals, having been seen for only a few

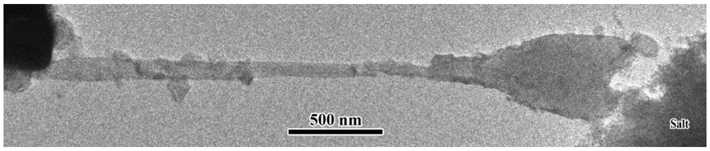

Figure 2: TEM image of a typical salt nanowire created after touching a gold tip to a salt crystal.

compounds. That table salt can stretch into nanowires comes as a surprise, because one is accustomed to the tiny salt crystals shaken onto food, and which appear brittle and shatter like glass into small pieces upon crushing.

One key to understanding the super-elongation is the disruption of the regular arrangement of Na^+ and Cl^- ions in the salt crystal lattice. In the TEM measurements, the electron beam used to image the sample creates holes in the crystal lattice, opening spaces for ions to rapidly migrate and "heal" the nanowire as it elongates. Chemical analysis shows that the beam also reduces a small fraction of the Na^+ ions in the salt to metallic sodium (Na), which enhances the ductility of the wire. In the IFM experiments, mechanical and adhesive perturbations are believed to alter the crystal lattice near the surface where the nanowires form.

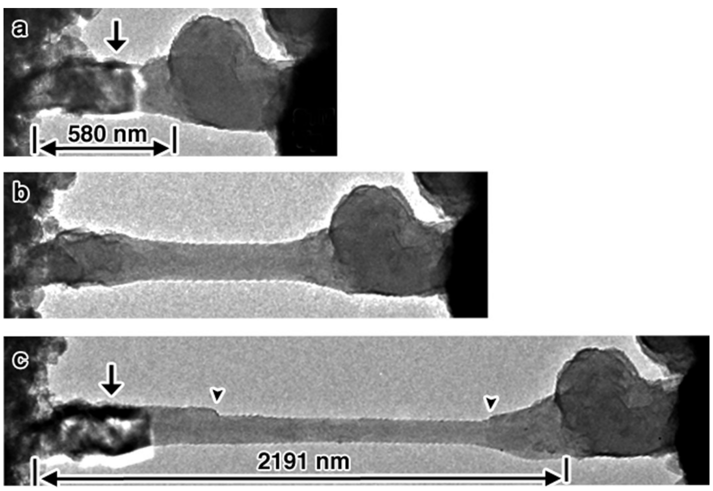

Figure 3: Time-lapsed TEM images showing super-elongation of a nanowire (a → c; time = 0, 256, and 502 sec., respectively). The gold tip (not shown) is adhered to the NaCl grain at the right side of these images. Arrows point to examples of steps and crystalline contrast on the nanowire surface. Roughness of the NaCl surface (left) appears exaggerated by the transverse imaging direction, which contracts the image.

This is the first demonstration of superplasticity in an ionic material at the nanoscale. Other materials that neck into nanowires far below their melting point have all been metals (e.g., gold, lead). Furthermore, the behavior of low-temperature-deforming, one-dimensional nanomaterials, such as carbon nanotubes and ceramic nanowires, would not have predicted similar behavior in ionic nanowires. The discovery may inspire new ways to create nanostructures through mechanical pulling or dissolvable templates. This work also raises broad questions about the presence of nanomaterials in the environment and their unseen influences. More fundamentally, the idea that common salt can be superplastic is a striking and unexpected example of how material properties can change when structures are reduced to nanoscale dimensions.

Reference

N. W. Moore, J. Luo, J. Y. Huang, S. X. Mao, and J. E. Houston, "Superplastic Nanowires Pulled from the Surface of Common Salt," *Nano Letters* **9(6)**, 2295 (2009).

Sandia National Laboratories

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